

# CARBONATE PLATFORMS

## FACIES, SEQUENCES AND EVOLUTION

EDITED BY MAURICE E. TUCKER,  
JAMES LEE WILSON, PAUL D. CREVELLO,  
J. RICK SARG AND J. FRED READ

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INTERNATIONAL ASSOCIATION OF SEDIMENTOLOGISTS  
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## Preface

This collection of papers on carbonate platforms is a companion to Special Publication 44, *Controls on Carbonate Platform and Basin Development*, published by the Society of Economic Paleontologists and Mineralogists in 1989. The latter was restricted in size for the sake of economy. Both volumes stem from the 1987 Los Angeles SEPM Research Symposium on carbonate platforms and basins, where many of the papers were presented orally or in poster sessions. This multi-national symposium derived from an international Penrose Conference on the subject held on the Isle of Capri in 1981 and organized by Professors Bruno D'Argenio and James L. Wilson.

Six of the papers in this book, those by Coccozza & Gandin, Elmi, Bice & Stewart, Ellis *et al.*, García-Mondéjar and Watts & Blome, were presented at the Los Angeles meeting and the others are recent additions.

The papers in this book are concerned with carbonate platforms and sequences from the Cambrian to Tertiary, and many derive from studies in the Tethyan region. Coccozza & Gandin compare Cambrian and Triassic carbonates from Sardinia and Tuscany in Italy, where carbonate platforms developed in rift-related settings. Gawthorpe & Gutteridge describe platform-margin bioclastic sand shoals from the Dinantian (Mississippian) of Derbyshire, central England, where facies, sequences and sand body lateral progradation are strongly controlled by sea-level changes. Based on studies of Carboniferous cycles, Walkden & Walkden present four computer models to simulate cycles in shallow-water carbonate, deep-water carbonate and mixed carbonate-clastic (deltaic environments). Middle Triassic (Muschelkalk) carbonate ramps in the Catalan Basin, Spain, are interpreted by Calvet, Tucker & Henton in terms of depositional systems tracts, but a strong tectonic control is argued for, rather than a simple eustatic forcing mechanism. Elmi describes the Ardèche carbonate platform (Triassic–Jurassic) from the western margin of the Subalpine Basin in France, bringing together many decades of field observations

from a classic area of limestone scenery. From the Apennines of Italy, Bice & Stewart describe the formation of isolated platforms and their later drowning as a result of tectonism and ecological factors. A tectonic, as well as eustatic control on Jurassic carbonate buildups is documented from the Lusitanian Basin of Portugal by Ellis, Wilson & Leinfelder. Arnaud-Vanneau & Arnaud apply a sequence stratigraphy–depositional systems tracts approach to the lower Cretaceous (Urgonian) carbonate platform of the Jura and northern Subalpine chains and demonstrate the importance of major eustatic sea-level changes as well as tectonic influences of basement faults. The effects of basement structure on carbonate facies patterns are also documented by Wilson from the Mesozoic of northeastern Mexico. Finally, Watts & Blome describe the consequences of closure of an ocean basin on an adjacent carbonate platform margin from the Cretaceous of Oman.

The papers in this book clearly show the diversity of carbonate platforms and their facies in the Phanerozoic and many illustrate the large-scale roles of tectonics and eustatic sea-level changes (second and third order) in controlling broad facies patterns and platform evolution. One major problem of course is distinguishing between these two overriding controls. An uncritical application of the Vail-Haq *et al.* sea-level curve is unacceptable these days, particularly for deducing eustasy. Many of the carbonate platform sequences described in this book contain small-scale cycles, commonly shallowing-upward, and the topical issue here is whether they are the result of orbital forcing in the Milankovitch band producing sea-level changes (fourth and fifth order) or some other mechanism (tectonic or sedimentary). Critical field observations and imaginative computer modelling are likely to make important contributions to this problem.

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## Carbonate deposition during early rifting: the Cambrian of Sardinia and the Triassic–Jurassic of Tuscany, Italy

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### ABSTRACT

The platform carbonates of early Palaeozoic age in Sardinia and of the early Mesozoic age in Tuscany were deposited in analogous tectono-sedimentary situations, the former linked to the Iapetus, the latter to the Tethyan, early stages of continental rifting. Both units represent isolated pericratonic platforms initiated and developed in an intra-cratonic rift. Deposition began with dolomites and evaporites and ended with limestones. Persistence of shallow-water deposition documents a continuous balance between carbonate production, subsidence and/or sea-level fluctuations. The syndimentary tectonic control during deposition resulted in high rates of sedimentation and differential subsidence. Three stages of platform collapse are recognized, which terminated shallow-water deposition. During the first stage the platforms were dissected into blocks and their differential movements produced contemporaneous tilting, uplift and drowning. During the second stage of collapse marginal plateaus were formed and neritic–pelagic sediments of various lithofacies overlapped sunken platform blocks. Nodular limestones were deposited on top of the more unstable blocks. The third collapse stage resulted in general deepening of the basins. The subsequent evolution of the basins reflects the different geodynamic development of the early Palaeozoic and early Mesozoic continental rifting. The former did not reach a spreading stage whereas the latter evolved into an open ocean. Climatic changes occurred during platform growth in both cases, and they provide further evidence of divergent movements connected with continental rifting.

### INTRODUCTION

The Cambrian of southwestern Sardinia and the Triassic–Jurassic of Tuscany (Fig. 1) are characterized by sequences which show a similar pattern of depositional evolution. In both cases, a carbonate platform developed on siliciclastic deposits and after drowning was buried by red, nodular limestones and then other pelagic deposits (Fig. 2).

The sedimentary evolution of early Mesozoic sequences in Tuscany has been related to the early phases of continental rifting associated with the opening of Tethys (Bernoulli & Jenkins, 1974; Bernoulli *et al.*, 1979). The Lower Palaeozoic sequences of Sardinia are related to early stages of continental break-up connected with the opening of

the Iapetus Ocean. However, this extensional phase in Sardinia gave way to oblique transform rifting that resulted in pull-apart basins and local gentle folding (Vai & Cocozza, 1986).

The aim of this paper is to compare the sedimentological characters of the two sequences in order to demonstrate that:

- 1 the Lower Palaeozoic and Lower Mesozoic carbonate platforms of Sardinia and Tuscany were tilted, isolated platforms, established, developed and drowned under a syndimentary tectonic regime related to early stages of intra-cratonic rifting;
- 2 the climatic change from arid to humid conditions recorded within the platform stage of both sequences suggests the shifting of the continental plates from arid to humid tropical areas as a consequence of divergent movements during continental rifting.

\* Deceased.

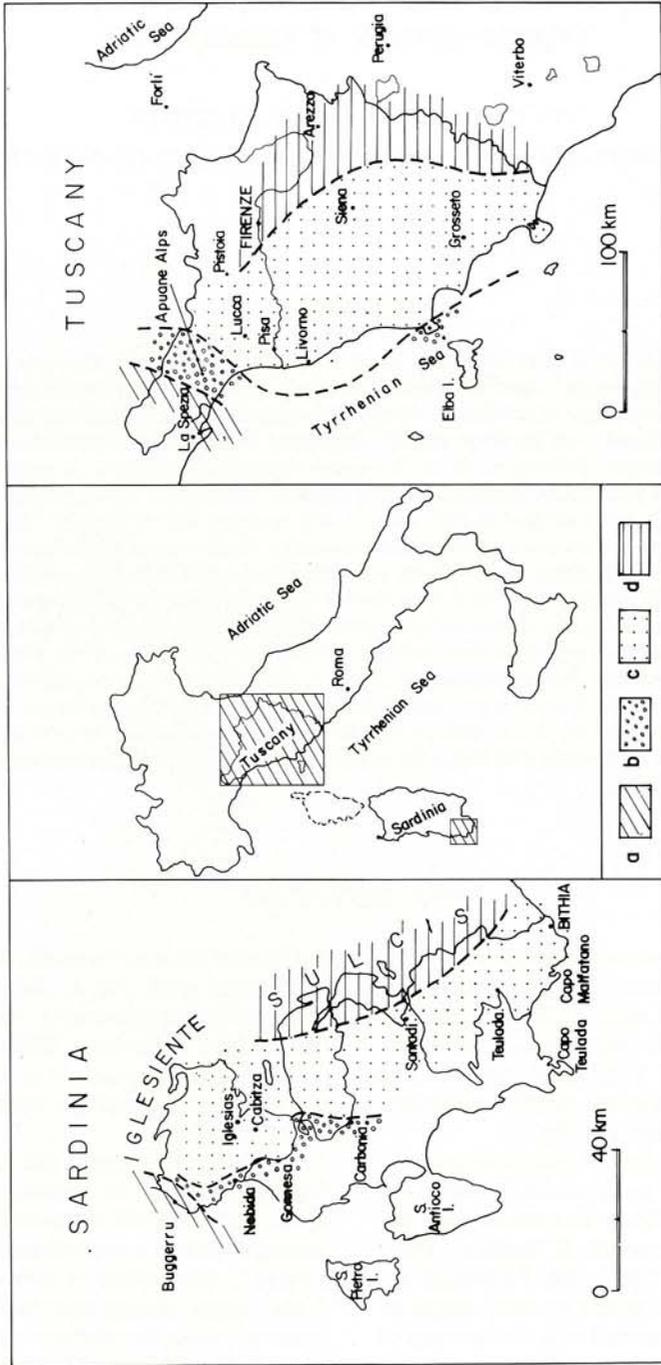


Fig. 1. Location maps and palinspastic reconstruction of Sardinian and Tuscan carbonate platforms. (a) basin; (b) western rimmed margin; (c) platform interior; (d) eastern margin.

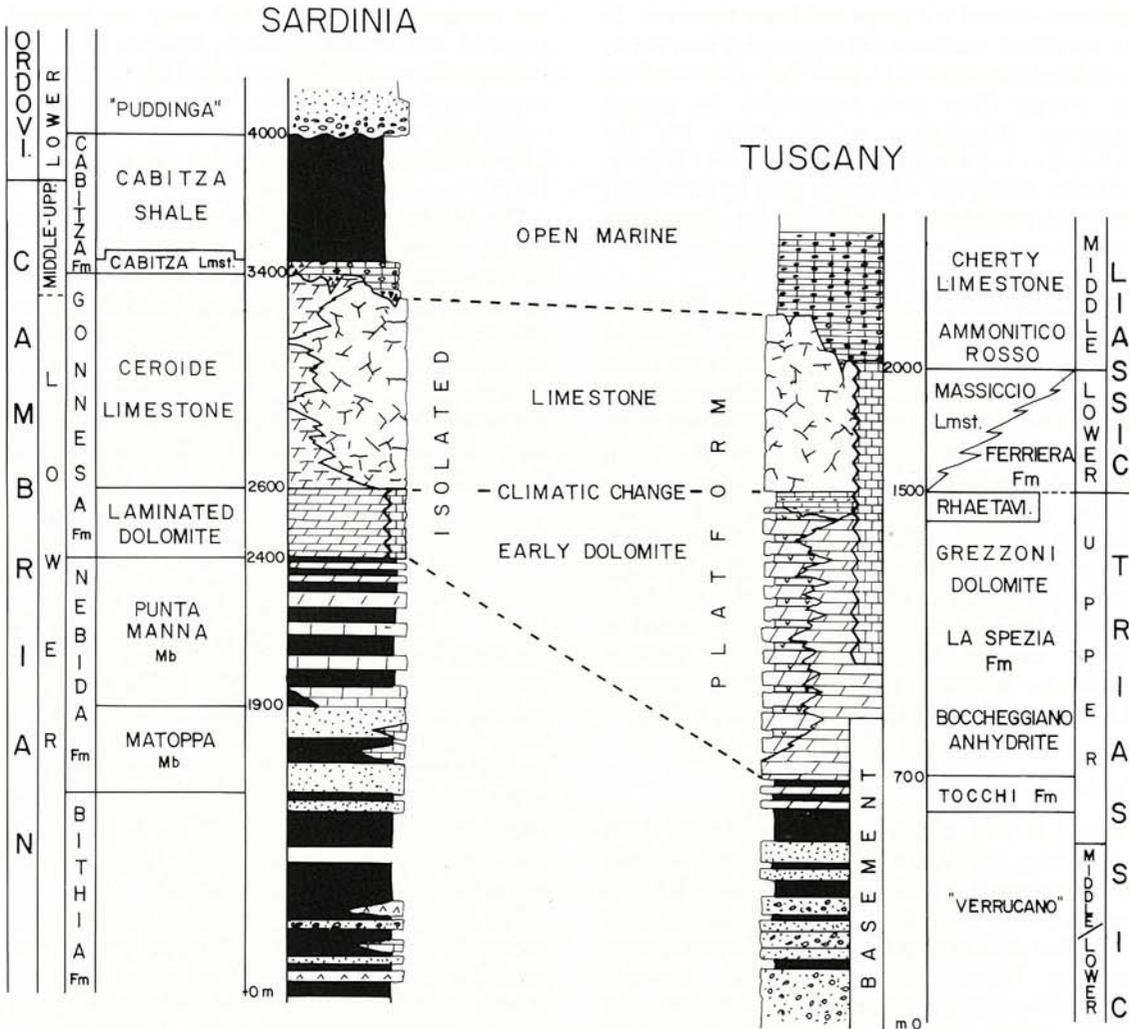


Fig. 2. Stratigraphic columns of Lower Palaeozoic in Sardinia and Lower Mesozoic in Tuscany.

## GEOLOGICAL SETTING

### Sardinia

Sardinia is the segment of the Meso-European Hercynian chain where the most complete Palaeozoic sequence in Italy is exposed. The Iglesias-Sulcis region in southwestern Sardinia corresponds to the External Zone of the Hercynian chain, Central Sardinia to the Nappe Zone and northern Sardinia to the Axial Zone (Carmignani *et al.*, 1986b). In Iglesias-Sulcis two sedimentary cycles are distinguished: Lower Cambrian to Lower Ordovician

and Upper Ordovician to Lower Carboniferous separated by the Sardinian angular unconformity of Arenig age. In Central Sardinia, early Cambrian carbonates are missing, and the sequence consists of Middle Cambrian-Lower Ordovician basinal siliciclastic deposits (Carmignani *et al.*, 1986b).

In southwestern Sardinia, the Sardinian phase, interpreted as a transpressional episode of a Caledonian oblique transform rifting (Vai & Cocozza, 1986), produced gentle E-W trending folds. During the Hercynian orogeny, three deformational phases gave rise to tighter N-S trending folds and local overthrusts, so that the present tectonic pattern of

Iglesiente–Sulcis is a dome and basin structure. To the north and southeast this structure is overlain by overthrust Cambrian (?) Lower Ordovician rocks of the Nappe Zone and surrounded by granite intrusions (Carmignani *et al.*, 1986a, b). The Caledonian and Hercynian structures were later re-activated during the Alpine orogeny by exclusively tensional movements resulting in the Campidano Graben and in the fracture along the Tyrrhenian coast.

The Lower Palaeozoic sequences of Sardinia were deposited on a proximal segment of the Gondwana continental shelf. The Cambrian–Lower Ordovician cycle starts with an Atdabanian (?) deltaic sequence (Bithia Formation), transgressive on a metamorphic, poorly-exposed basement (Gandin *et al.*, 1987). During Lower Cambrian times a shallow-water carbonate platform developed and in the Middle Cambrian this collapsed, to be replaced by an intra-continental basin lasting until Tremadocian (Gandin, 1980; Carannante *et al.*, 1984; Courjault-Radè & Gandin, 1986). The deeper part of this basin is at present exposed in the Nappe Zone (eastern Sardinia) beyond the Campidano Graben (Carmignani *et al.*, 1986b; Gandin *et al.*, 1987).

### Tuscany

Tuscany is part of the northern Apennine chain built during the Alpine orogeny. Triassic–Jurassic sediments occur in different tectonic units that have been detached from their basement and thrust over each other in an eastern direction. The more internal Ligurian Nappe comprises Upper Jurassic–Cretaceous oceanic deposits with ophiolites. The Tuscan Nappe that has been locally sheared off along Upper Triassic evaporites, consists of: (1) an external Tuscan Domain of Palaeozoic metamorphic basement and Mesozoic–Tertiary cover and (2) an internal Tuscan Domain (Apuan Alps Zone and Massa Zone) of a metamorphosed Mesozoic cover on Palaeozoic basement (Decandia *et al.*, 1980). At the end of the compressive orogenic phases (Lower Miocene) extensional tectonics produced NW–SE trending graben-and-horst structures, later dissected by a NE–SW trending transcurrent-fault system.

As a consequence of their tectonic history, the Lower Mesozoic deposits of the Tuscan Nappe are poorly exposed. However, they maintain their original palaeogeographic relationships without the need for major palinspastic corrections, except for the Livorno–Sillaro dextral transcurrent fault that puts

the marginal facies in contact with the internal facies of the Triassic–Jurassic platform (Fig. 1). Palinspastic reconstructions of the Triassic–Jurassic sequences place the Tuscan Units on the European continental margin of the Ligurian Ocean that was a N–S trending segment of Tethys (Bernoulli *et al.*, 1979).

The Alpine depositional cycle starts with the Middle–Upper Triassic Verrucano arid-climate redbeds sedimented on a continental basement already affected by extensional tectonics and Middle Triassic ‘abortive’ rifting (Gandin *et al.*, 1982). From Norian to Hettangian a carbonate platform existed, but at the beginning of the Sinemurian it collapsed and an epicontinental basin was established, which progressively deepened towards the Ligurian Ocean (Decandia *et al.*, 1980).

### CAMBRIAN OF SARDINIA

The Cambrian sequence is up to 3500–4000 m thick, with lateral variations, especially in the carbonate unit. Its base (Bithia Formation, Lower Cambrian–?Atdabanian) is exposed only in the southernmost part of Sulcis region because of the structural setting of the area and the occurrence of Hercynian granite intrusions (Carmignani *et al.*, 1986a). It is overlain with angular unconformity by post-Arenig conglomerates and megabreccias (‘Puddinga’).

The Lower Cambrian to Lower Ordovician sequence (Figs 2 & 3) was deposited on an epicontinental shelf where deltaic terrigenous sediments (Bithia Formation) were gradually replaced by carbonates (Nebida Formation). The exclusively carbonate Gonnese Formation consists of two informal members: Laminated Dolomite (*Dolomia rigata*) at the base, and Ceroide Limestone (*Calcare ceroide*) at the top (Coccozza, 1979). The carbonate platform underwent fragmentation, uplift and drowning and was finally buried by further shelf carbonates (*Cabitza Limestone–Calcare nodulare*) and then by basal siliciclastics (*Cabitza Shales–Scisti di Cabitza*). The upper part of the sequence has probably been removed during the emergence and deposition of the Puddinga (Coccozza, 1969; Carannante *et al.*, 1984; Gandin, 1990a).

Biostratigraphy in Sardinian Cambrian is mainly based on trilobites and archaeocyathids and most of these are endemic species and genera so that the biostratigraphic zonation cannot be precisely

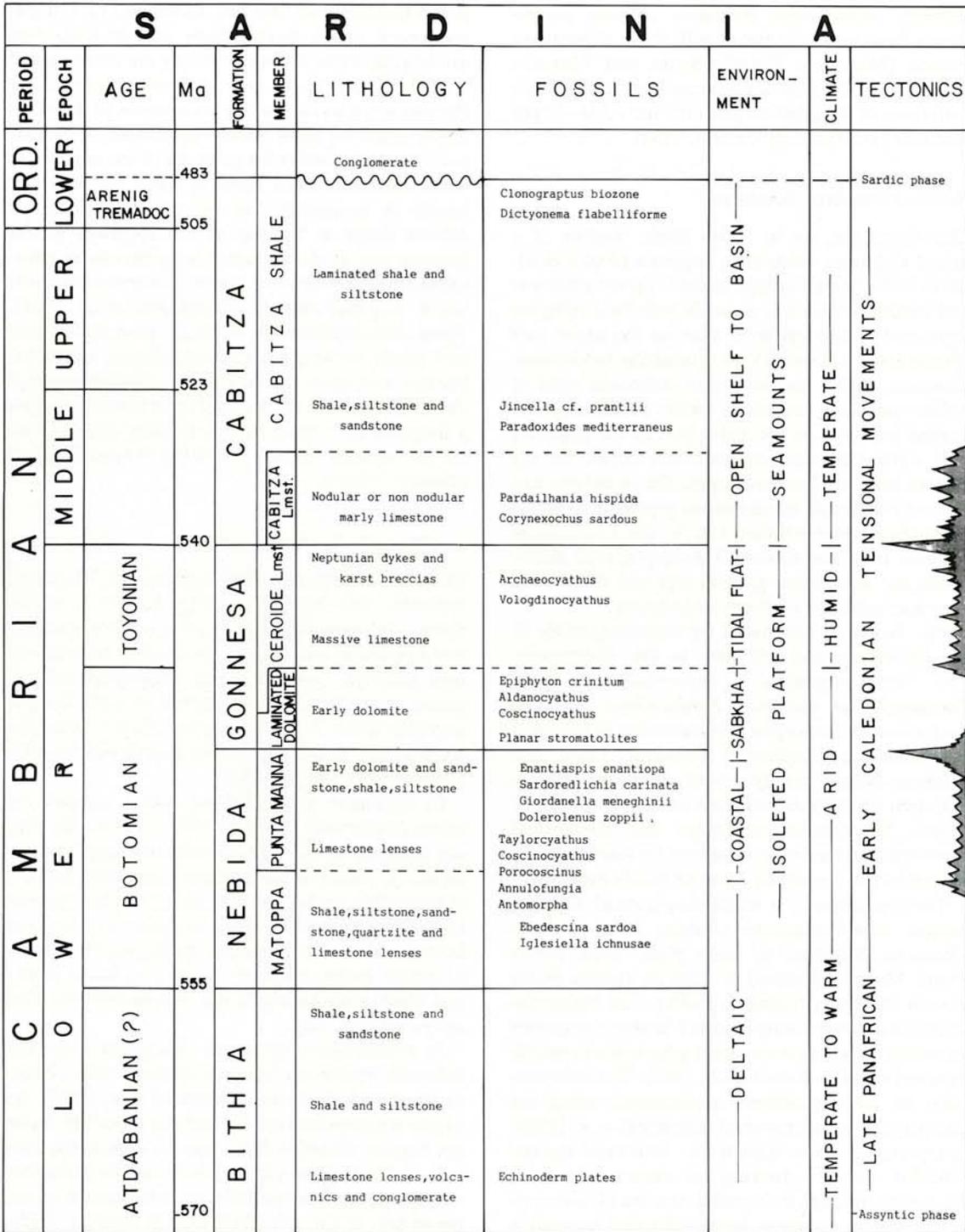


Fig. 3. Stratigraphy, depositional environments and tectonic events of the carbonate platform in Sardinia.

defined. Nevertheless Sardinian trilobite assemblages have been correlated with those of southern France (Montagne Noire), Spain and Morocco (Rasetti, 1972) and archaeocyathan assemblages with those of the Siberian platform and Altai–Sayan fold belt (Debrenne & Gandin, 1985).

#### Nebida Formation (Botomian)

This formation, up to 800 m thick, consists of a mixed carbonate siliclastic sequence (Figs 2 & 3). In the lower part (Matoppa Member) green siltstones and sandstones include mounds built by *Epiphyton* algae and archaeocyathids, whereas the upper part (Punta Manna Member) has alternating sandstones, siltstones, shales and lenticular carbonate units of oolitic–oncolitic limestone with small archaeocyathid buildups. In the upper part of the sequence only early dolomite intercalations occur. In the eastern and southeastern areas, the limestone and the early-dolomite intercalations gradually decrease in thickness and number and in the easternmost sections they are absent. The intercalated siliclastics are mostly fine-grained silts and shales with rare intercalations of quartz–sandstone.

The fauna is dominated by archaeocyathids in the limestones and trilobites in the siliclastics. The archaeocyathids (*Taylorcyathus rectus*, *Coscinocyathus dianthus*, *Porocoscinus*, *Annulofungia* and *Anthomorpha*) are indicative of a general Botomian age (Rozanov & Debrenne, 1974). The trilobite fauna, mainly found in Punta Manna Member, includes *Hebediscina sardoa*, *Dolerolenus zoppii*, *Giordanella meneghinii* and *Enantiaspis enantiopa* and has been correlated by Rasetti (1972) to part of the Nevadella Zone of North America.

The formation is a shallowing-upward deltaic–marine mixed sequence evolving from prodelta (Matoppa Member) to delta plain–coast (lower Punta Manna Member) to sabkha (upper Punta Manna Member) (Gandin, 1990a). The facies distribution of lower Punta Manna Member documents an oolitic margin in the western edge of the presently exposed area (Bechstadt *et al.*, 1985). The interpretation of the depositional environment along the eastern edge is controversial. Bechstadt *et al.* (1985) interpreted it as a siliclastic, backshoal–lagoon/tidal-flat complex flanking an eastern mainland. However, although the detailed analysis of this member is still in progress, some evidence suggests a deeper-water setting in the eastern and southern areas: (1) the siliclastic fraction is dominated by

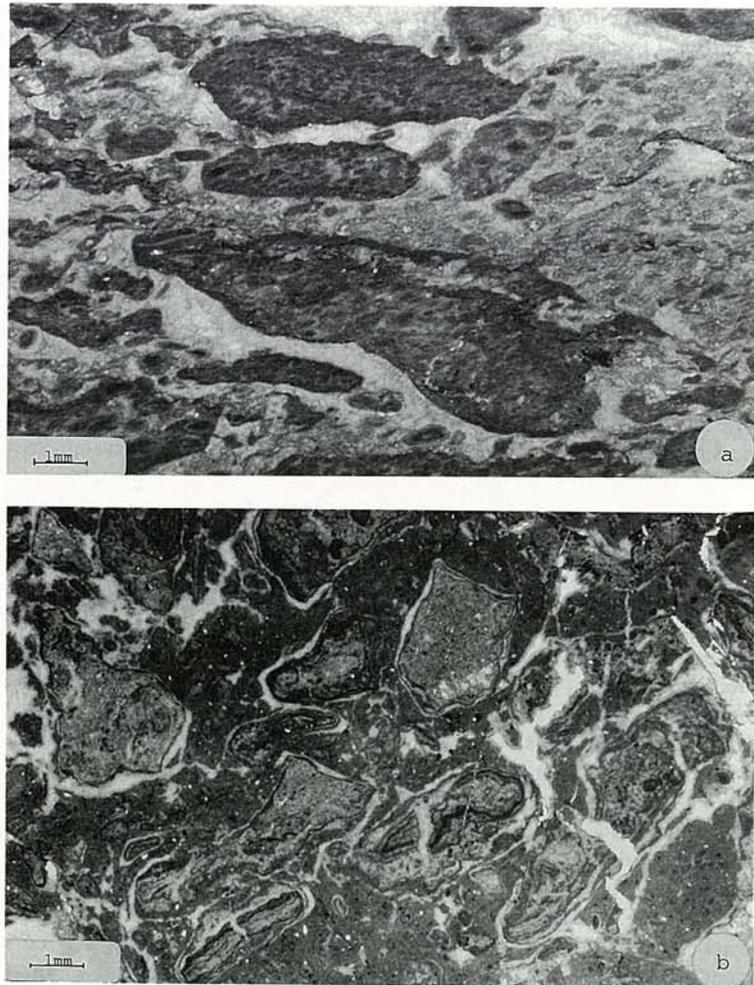
shales and silts, with rare fine sandstones; (2) channel sequences, ripple marks, flaser and cross-bedding are lacking in the east whereas they are common and well developed in the west; (3) palaeocurrents for the western area, indicate a provenance of the siliclastic material from north–northwest. A similar source is suggested by the grain size of the sandstones which decreases from north to south and east (research in progress); and (4) the early-dolomitic sabkha facies at the top of the sequence in the western area is characterized in Iglesias by intercalations of goethite-rich layers, interpreted as freshwater, bog-lake deposits (Carannante *et al.*, 1975). These intercalations are replaced towards the east and south by lenses of pseudomorphs of barite. Farther east both the tidal-flat early-dolomite and the barite lenses disappear. All these features suggest a deeper-water rather than a tidal-flat environment for the eastern outcrops of Punta Manna Member (Gandin, 1990a).

#### Laminated Dolomite (Botomian)

This unit consists of evenly bedded and laminated dolomite, 200–250 m thick (Figs 2 & 3). In north-western Iglesias (Buggerru area), archaeocyathids and *Epiphyton crinitum* are enclosed in oncolids and rare trilobite fragments and archaeocyathids in planar stromatolites. The poorly diversified archaeocyathid fauna is composed of typical Botomian genera such as *Aldanocyathus* and *Coscinocyathus* (Debrenne & Gandin, 1985).

In Iglesias and northern Sulcis, shallowing-upward (intertidal to supratidal) cycles prevail; they are made up of: (1) banded dolomicrosparitic mudstone; (2) planar or wavy stromatolites (Fig. 6a); (3) stromatolites with fenestrae; and (4) vadose pisolite (*sensu* Esteban, 1976) (Fig. 4c) and/or desiccation breccias. Thin, discontinuous, locally silicified layers of oolitic grainstone occur as well as barite lenses and chert nodules which are pseudomorphic after anhydrite (Fig. 6b).

In northwestern Iglesias (Buggerru area) the dolomite mudstone facies alternates with homogeneous black limestone (Bechstadt *et al.*, 1985); the planar stromatolites prevail and the supratidal facies are lacking. Oncolitic facies contain archaeocyathids and skeletal algae (*Epiphyton*) and stromatolites entrapping archaeocyathids are intercalated in the upper part of the unit (Debrenne & Gandin, 1985). In eastern Sulcis this unit thins out; the early dolomite gives way to limestone and only the even-



**Fig. 4.** Facies at the arid/humid climate transition: Laminated Dolomite/Ceroide Limestone boundary. (a) Vadose facies at the base of the platform consisting of limestone intraclasts and calcite cements. (b) Vadose facies at the top of the sabkha complex consisting of early dolomite intraclasts and dolomitic cements.

laminated stromatolitic facies persists (Gandin, 1990a).

The Laminated Dolomite represents a sabkha complex whose style of deposition has been related to the Trucial Coast model (Carmignani *et al.*, 1986a; Gandin, 1990a). However, in the Lower Cambrian sabkha of Sardinia, carbonate deposition prevailed over evaporitic sedimentation which is only recorded by small pseudomorphic chert nodules and barite lenses.

The areal distribution of the facies from west to east indicates a different morphology of the two ends of the platform (Fig. 12): (1) a western higher-energy margin, with patch-reefs built by archaeocyathids and *Epiphyton*, whose remains are now found trapped in both the stromatolites and

oncolites; and (2) an eastern ramp-like margin where, in a low energy shallow-subtidal environment, the stromatolites developed and were not dolomitized. This morphology as well as the complete absence of terrigenous material suggests that this sabkha developed on an isolated platform.

#### **Ceroide Limestone (Upper Botomian to Lower–Middle Toyonian)**

This unit is a massive body of pearl-grey limestone whose thickness ranges from 160 to 800 m (Figs 2 & 3). The transition from the Laminated Dolomite is gradational and marked by a continuous belt of black dolomitic limestone. By way of contrast, the upper boundary is an unconformity with pink,

bedded marly limestone of Cabitza Formation. The Ceroide Limestone is locally affected by dolomitization (Grey Dolomite). In its upper part karstic features, calcite veins as well as breccia bodies are present.

Common fossils are echinoderm plates and trilobite fragments. Rare archaeocyathids and *Epiphyton* occur in the upper part of the limestone body, only in the western area. The archaeocyathids form assemblages with *Archaeocyathus altaicus*, *A. cf. grandis*, *A. kusmini* and *Vologdinocyathus tener* indicating a Lower–Middle Toyonian age (Debrenne & Gandin, 1985).

The Ceroide Limestone is noticeable for its great lateral variation in thickness in adjoining sections and complex facies mosaic (Fig. 5). The following facies have been recognized:

- 1 Tidal flat. Fenestral stromatolitic boundstone (Fig. 7f), and vadose pisolite (*sensu* Esteban, 1976) (Fig. 4a), with rare trilobite fragments.
- 2 Internal lagoon. Mudstone, peloidal wackestone and packstone.
- 3 Shoal. Three different facies associations have been found: type (1) consists of skeletal (*Epiphyton*) boundstone with local archaeocyathid mounds (Fig. 7b); type (2) is well-sorted ooid and oncoid grainstone (Fig. 7d). In both facies, trilobite and echinoderm fragments are common; and type (3) is represented by unsorted intraclast grainstone with lumps, peloids and rare trilobite and echinoderm fragments (Fig. 7h).
- 4 Open lagoon. Skeletal or poorly sorted granular wackestone, laminated mudstone and marly intercalations. The grains are oncoids, micritized grains and intraclasts, that are probably reworked calcrete clasts, and minor quartz silt and clay. Fossils are represented by trilobite and echinoderm fragments, commonly concentrated in small lenses.

These facies, indicative of a shallow-water platform, have a characteristic non-cyclic vertical distribution and are laterally discontinuous (Fig. 5). There is no suggestion of a regressive trend through this unit although there is clear evidence of exposure at the end of the Ceroide Limestone deposition. However, at the base of the sequence, everywhere in the central part of the platform, tidal-flat or lagoonal facies occur.

The areal distribution of the facies indicates an isolated platform bounded by epicontinental basins (Fig. 12). From west to east the following time equivalent facies can be recognized (Fig. 1):

- 1 Shelf. This occurs in a narrow belt along the

coast of the Tyrrhenian sea (Buggerru area) where the well-stratified Ceroide Limestone has open-lagoon facies and in the upper part of a few sections in the platform interior where thin shale layers are intercalated with open-lagoon facies.

- 2 Platform rimmed margin. Along the western edge of the platform *Epiphyton* buildups with local archaeocyathid mounds interfinger with small oolitic–oncolitic shoals (type 1 and 2 shoal facies).
- 3 Platform interior. This consists of irregularly alternating restricted-lagoon and tidal-flat facies.
- 4 Platform ramp-like margin. In the eastern area, type 3 shoal facies interfingers with open-lagoon facies. Here the limestone decreases in thickness, is evenly bedded, and contains thin marly and shaly intercalations, slump structures (Coccozza, 1969) and channels.

#### Cabitza Limestone (Middle Cambrian)

This unit is made up of bedded, locally nodular, fossiliferous limestone alternating with red or green silty shales up to 80 m thick. It unconformably overlies the Ceroide Limestone with a sharp contact locally marked by a palaeokarstic surface and slope breccias. It contains rich assemblages of early Middle Cambrian age (Rasetti, 1972), including trilobites (*Corynexochus sardous*, *Pardailhanian hispida*), echinoderms, *Chancelloria*, brachiopods, hyolithids and miscellaneous sponge spicules. Limestone and shale facies are highly variable in thickness and colour. The latter ranges from black to grey, green, pink, red or yellow. Three irregularly alternating different lithotypes can be found: (1) massive, evenly-bedded limestone with wavy shaly partitions; (2) nodular marly limestone (Fig. 8a); and (3) alternating calcareous and shaly planar laminae (Gandin, 1990a, b). The limestone facies are skeletal wackestones and packstones with a diverse open-marine fauna (Fig. 8b) and silt-sized quartz grains, pyrite and hematite. The latter gives the red colour to the intercalated red shales (Lecca *et al.*, 1983).

The sedimentary features and fossil content of this unit are on the whole indicative of a more or less restricted shallow-shelf environment, where pelagic siliciclastics and residual 'terra rossa' coming from the karstified platforms interfered with the *in situ* carbonate production. The genesis of the nodular structure of the limestone can be mainly related to compaction and dissolution of sediments with non-homogeneous density gradients, triggered by tectonic instability of the shelf. This facies was therefore

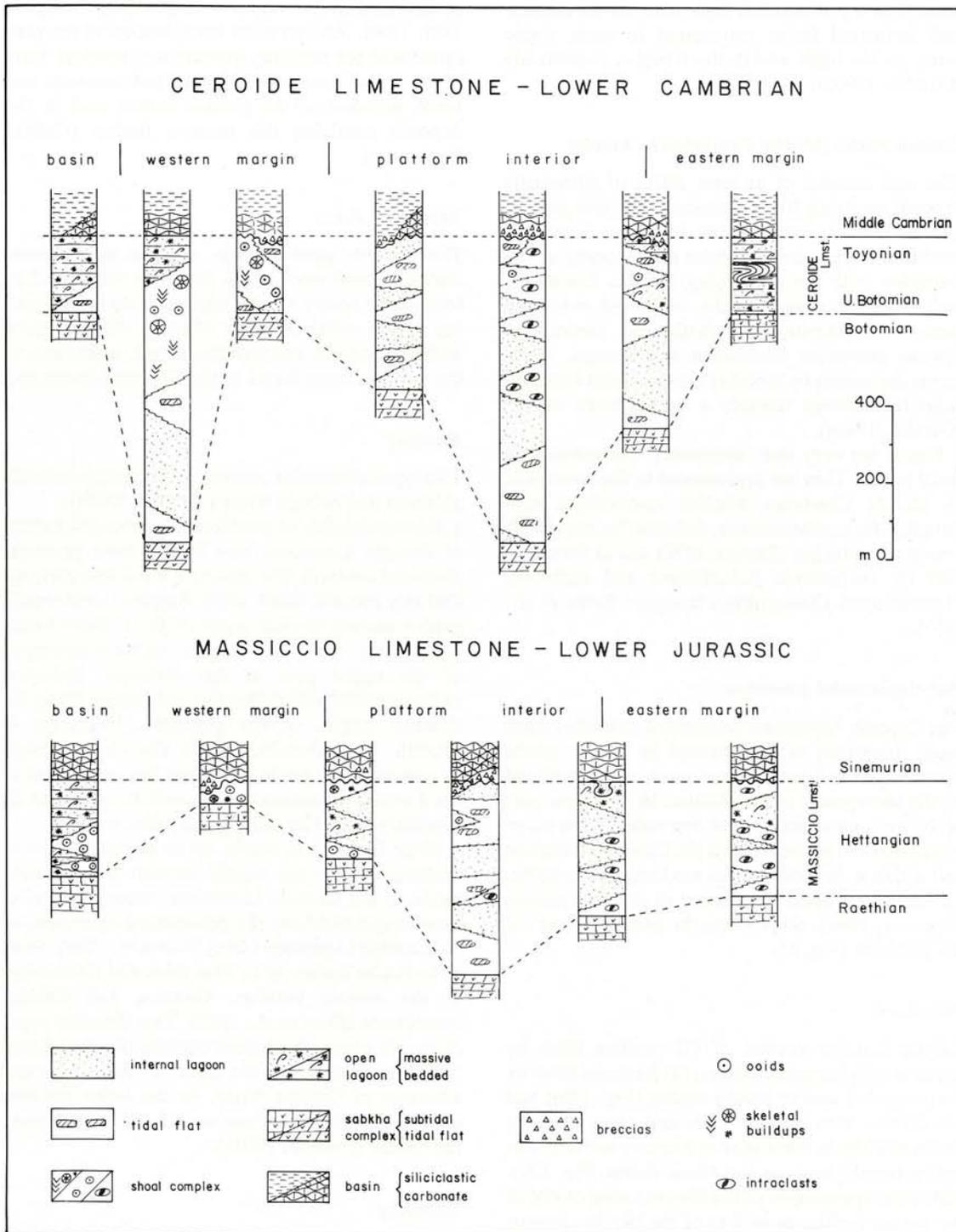


Fig. 5. Vertical and lateral facies distribution across Lower Cambrian Ceroides platform in Sardinia and Lower Jurassic Massiccio platform in Tuscany.

located on top of unstable highs whereas the massive and laminated facies correspond to more stable zones on the highs and in the troughs, respectively (Gandin, 1990b).

#### Cabitzia Shales (Middle Cambrian to Arenig)

This unit consists of at least 600 m of siliciclastic deposits evolving from siltstones with fine-grained quartz-arenite intercalations to thinly laminated mudstones. Limestone nodules occur locally at the transition with the underlying Cabitzia Limestone and disappear upwards. The laminated mudstone facies, characterized by rhythmical lamination, ripples, convolute lamination and slumps, documents deposition by turbidity currents, and indicates a gradual change towards a deeper-basin setting (Gandin, 1990a).

Fossils are very rare, commonly concentrated in small lenses. They are represented in the lower part by Middle Cambrian trilobite assemblages with *Paradoxides mediterraneus*, followed by *Jincella* cf. *prantli* assemblages (Rasetti, 1972) and in the upper part by *Dictyonema flabelliforme* and acritarchs (Tremadocian *Clonograptus* biozone; Barca *et al.*, 1987).

#### Post-depositional processes

The Ceroide Limestone underwent extensive fresh water diagenesis as documented by blocky calcite cements. Marine cements are poorly developed and locally show traces of dissolution. In the upper part of the unit, palaeokarsts and neptunian dykes occur whereas at the boundary with the Cabitzia Limestone and within it, breccias bodies are locally found (Fig. 2). Contorted beds, interpreted as cohesive slumps (Coccozza, 1969), occur along the eastern margin of the platform (Fig. 5).

#### Paleokarst

Karstic features consist of (1) cavities filled by breccias with hematitic matrix; (2) fractures filled by fibrous-radial and/or blocky calcite (Fig. 10b); and (3) cavities with smooth walls and pipes filled by shales of Cabitzia lithologies or breccias and alternating carbonate laminae and black shales (Fig. 10a). Stable isotope analysis of the fibrous radial calcite of the karstic cavities as well as of the blocky cements of the Ceroide Limestone, support a meteoric origin for the diagenetic waters from which the calcite was

precipitated ( $\delta O^{18}$  values = 12.57 PDB; Gandin & Turi, 1990). An extensive karstification of the platform, with the resulting formation of residual 'terra rossa' is also documented by the red hematitic material included in the breccia matrix and in the deposits overlying the massive bodies (Cabitzia Limestone).

#### Neptunian dykes

The Ceroide platform was affected by extensive fracturing and most of the fractures were filled by fresh-water sparry calcite. However, there are small (up to 1 m wide) fractures filled by silicified marls with echinoderm and trilobite debris, equivalent to the homogeneous facies of the Cabitzia Limestone.

#### Breccias

Two types of breccias occur at the boundary between platform and pelagic facies (Gandin, 1990b):

1 Karstic breccias of pebble-size, subrounded clasts of Ceroide Limestone that locally have pressure-dissolved contacts. The matrix is a red hematitic silt that also contains small calcite fragments and locally grades upward to pink marls of the Cabitzia Limestone facies. The clasts are derived from lithotypes of the upper part of the platform, including archaeocyathid-rich facies that only occur along the western margin of the platform (Debrenne & Gandin, 1985; Gandin, 1990b). The breccias occur in palaeokarstic sinkholes within the upper part of the Ceroide Limestone or in pockets exactly at its boundary sealed by the Cabitzia Limestone.

2 Slope breccias of blocks up to several meters in diameter; these are mainly derived from various facies of the Ceroide Limestone although some of them originated from the dolomitized equivalent of the Ceroide Limestone (Grey Dolomite). They occur as lenticular bodies up to 10 m thick and 100 m long, at the contact between Gonnesa and Cabitzia Formations (Boni *et al.*, 1981). Two different types of matrix occur: the former consists of marly facies of Cabitzia Limestone, the latter of black shales and siltstones of Cabitzia Shale. In the latter instance clasts of Cabitzia Limestone can also be found among the blocks (Gandin, 1990b).

#### Slumping

Deformation structures and associated breccias are common along the eastern margin of the Ceroide

Limestone platform (Cocoza, 1969) and similar structures also occur along the western edge (Balassone *et al.*, 1985). Slump structures have also been reported from the Laminated Dolomite in the western and eastern margins of the platforms by Bechstadt *et al.* (1985). The deformation structures reported by them from the western stromatolitic – evaporitic facies are associated with that shown in Fig. 6a and similar to that of Fig. 6c and, therefore, are here interpreted as the result of plastic movements of now-vanished evaporites and connected with later tectonics.

The slump structures occurring in the eastern region and referred by Bechstadt *et al.* (1985) to the Laminated Dolomite, actually occur 20–50 m below the contact with the Cabitza Limestone and affect either the laminated or massive mudstone facies of the Ceroide Limestone in the ramp-like margin of the platform.

### Ceroide platform evolution

#### *Incipient platform*

The first isolated platform stage is represented by the Laminated Dolomite deposited in a tidal-flat sabkha system flanked to the west and east by open-sea waters (Fig. 12 I). As a result of the present structural setting, the supposed basin sediments are not exposed. However, evidence of their existence is provided by: (1) lack of land-derived siliciclastics; (2) development of calcareous facies towards the western and eastern edges of the platform; and (3) the presence on the western edge of archaeocyathids and algal (*Epiphyton*) buildups. Moreover, the occurrence of normal marine organisms to the west is suggestive of a steeper margin there than in the east.

The depositional characters of the Laminated Dolomite and the rather uniform cyclic deposition and sediment thickness in the platform interior indicate regular, moderate subsidence of the platform and/or slow sea-level fall under an arid climate.

#### *Ceroide Limestone platform*

The vertical and lateral distribution of the facies and the lack of terrigenous material in the Ceroide Limestone are indicative of an isolated platform consisting of a wide, internal shallow-lagoon/tidal-flat system with asymmetric margins (Fig. 12 II). Throughout its growth the platform interior maintains a non-cyclic internal-lagoon/tidal-flat

deposition. This behaviour suggests that carbonate production kept up with irregular subsidence.

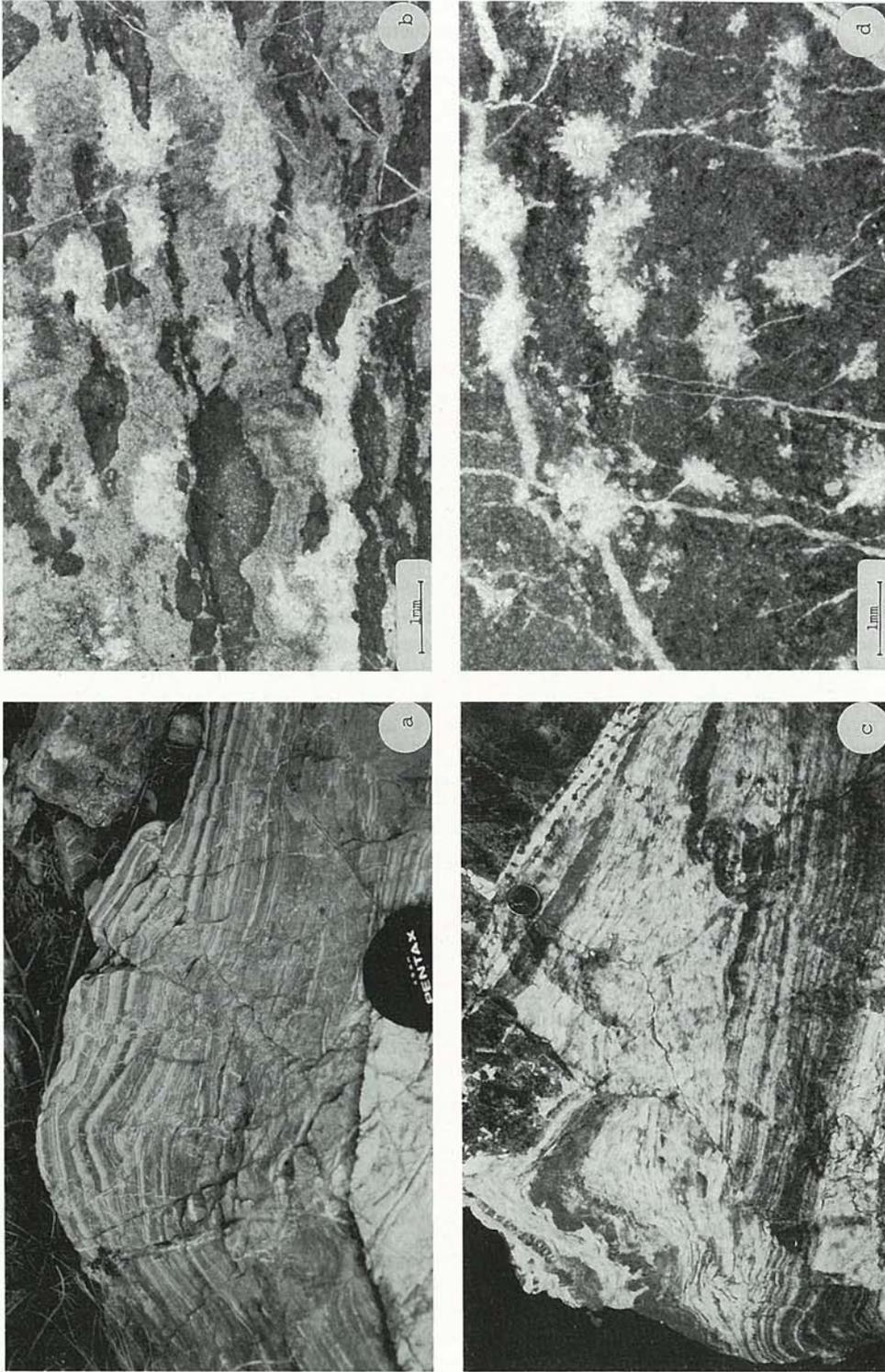
The western margin was built by organic reefs (algae and minor archaeocyathids) and oolitic shoals. Its growth appears to have been controlled by a rapid relative sea-level rise that favoured up-building and prevented lateral outgrowth. To the west the shoal was flanked by a deeper basin, whose existence can be inferred by the occurrence of a narrow belt of bedded, open-lagoon facies (Buggerru area).

The eastern margin, wider than the western one, had a ramp-like profile. It was mainly constructed by bedded marine lime mudstones containing a small amount of fine-grained siliciclastics. The limestone thickness gradually decreases toward the eastern Sardinia (Nappe Zone) siliciclastic basin. In this area too, although the transition to the basin is not exposed for structural reasons, the thickness reduction, the occurrence of siliciclastic material and the bedding of the Ceroide Limestone indicate a clear trend towards a deeper basin (Gandin *et al.*, 1987).

Within the platform the complex internal stratigraphy, the non-cyclic recurrence of the facies and the great thickness variability imply differential subsidence of the different areas. Rate of sedimentation can be estimated to be in the order of 30–160 mm  $10^{-3}$  yr assuming that the time interval of deposition from Upper Botomian to Lower–Middle Toyonian was 5 Ma. (Toyonian is the upper stage of Lower Cambrian in the Russian subdivision of Cambrian (Rožanov & Sokolov, 1984). This stage was previously included in the Lenian whose duration is 15 Ma (Harland *et al.*, 1982). The Toyonian, which according to Rožanov & Sokolov (1984) is a short time interval is assumed here to have lasted 5 Ma). The high rates of sedimentation compare well with the values reported from the Tethyan Triassic platforms and the deposits of modern platforms (D'Argenio, 1970; Bernoulli, 1972; Wilson, 1975). The depositional behavior of the Ceroide platform deposits reflects an irregular and rapid subsidence balanced by carbonate production under a humid climate.

#### *Platform exposure*

The deposition of Ceroide Limestone ended when most of the platform emerged in late early Cambrian time (Fig. 12 III). Owing to the differential subsidence occurring during the previous depositional period, not all the platform sections were exposed



**Fig. 6.** Arid platform. Lower Cambrian Laminated Dolomite (above) and Upper Triassic Boccheggiano Anhydrite (below). (a) Stromatolitic laminites affected by tectonic deformation resulting from the former occurrence of sulphates. (b) Pseudomorphs of sulphate nodules in early-dolomitic mudstone. (c) Stromatolitic laminites and anhydrite layers tectonically deformed by the plastic behaviour of sulphates. (d) Anhydrite nodules and rosettes in early-dolomitic mudstone.

and the more distal marginal areas were never uplifted. Negative zones at the top of the Ceroide Limestone are characterized by restricted-lagoon, laminated facies including thin shaly layers in the marginal zones.

Positive zones were fractured and subjected to karstic dissolution producing cavities and clasts of the upper early-lithified sediments. The lack of well-developed regressive sequences attests to a rapid uplift of the blocks that was responsible for circulation of meteoric waters and consequent extensive fresh-water cementation of sediments not yet completely lithified in the marine environment, and local dolomitization.

#### *Platform collapse*

At the beginning of Middle Cambrian the previously uplifted platform began to collapse and drown (Fig. 12 IV). Biostratigraphic data and sedimentological evidence indicate that the drowning was differential and discontinuous. The drowning of the platform was achieved through two main stages leading to a marginal-plateau structure (Fig. 12).

A first drowning event in the early Middle Cambrian (*Pardailhania hispida* horizon) resulted in the deposition of Cabitza Limestone. Most of the platform was rather suddenly flooded to neritic depth. Exposure and shallow-water deposition persisted only on a number of blocks. The residual hematitic material, previously produced on the exposed platform, was in part swept out and mixed with pelagic clays and autochthonous carbonates. Fissures and karstic cavities, not yet filled by calcite or karstic breccias, were filled with marine unconsolidated sediment. Slope breccias accumulated at the fault scarps, mostly along the western and eastern margins of the platform (Boni *et al.*, 1981; Gandin, 1990b) and were covered by Cabitza lime muds. Most of the breccias occur at the Ceroide Limestone–Cabitza Limestone contact, but smaller breccia units occur also within the Cabitza Limestone. Their subrounded clasts of Ceroide Limestone lithofacies indicate local persistence of emergent Ceroide blocks. Deposition of Cabitza Limestone was characterized by carbonate production rhythmically alternating with siliciclastic material. During carbonate intervals a well-diversified benthic fauna developed. The block-and-basin topography of the seafloor resulted in two different facies of the Cabitza Limestone. The massive calcareous facies was formed on structural highs

whereas the laminated marly facies was deposited in deeper-water settings. The nodular facies occurs only locally and at different stratigraphic levels of the sequence. Its genesis records instability of the blocks and their differential drowning.

A second drowning event took place later in the Middle Cambrian (*Paradoxides mediterraneus* to *Jincella* horizons). It led to the final foundering of the platform and to resumption of connections with the mainland. Quartz sands were at first transported in the Cabitza Shale basin in which only later exclusively siliciclastic distal turbidites were deposited. The few structural highs that were left exposed along the western margin during deposition of Cabitza Limestone also drowned and the karstic cavities were filled by black or grey Cabitza Shales. Megabreccias made up of Ceroide Limestone and locally Cabitza Limestone clasts accumulated at the fault scarps mostly along the western margin of the platform and were embedded in black muds and silt (Gandin, 1990b).

#### *Climatic control*

The Ceroide Limestone is a pure calcareous unit in which no traces of early dolomitization have been found in the widespread intertidal–supratidal facies. The *Epiphyton*-dominated buildups have been interpreted as indicative of normal marine water (Debrenne & Gandin, 1985). Moreover, the abundance of blocky calcite cements and the average limestone isotopic values ( $\delta O^{18} = -8.9$  PDB) indicate a consistent supply of meteoric waters during the early diagenetic processes of the Ceroide Limestone (Gandin & Turi, 1990). These features imply humid tropical conditions and the same humid regime persisted when, with the uplift of the platform, the sediments underwent extensive fresh-water cementation, karstification and local dolomitization.

The lower boundary of the Ceroide Limestone platform is marked by a rather sharp transition from the underlying Laminated Dolomite. The latter was deposited in an arid, evaporitic tidal flat where the carbonates underwent early dolomitization.

A climatic change from arid to humid has been proposed to explain why Ceroide Limestone and Laminated Dolomite sediments went through such different early diagenetic processes (Fig. 4), since they were both laid down in the same tidal-flat conditions (Gandin, 1980).

## MESOZOIC OF TUSCANY

The Upper Triassic–Middle Liassic carbonate sequence ( $\approx 2000$  m thick) is underlain by continental deposits (Verrucano), which lie unconformably on the Palaeozoic basement or on Middle Triassic sediments. In the External Tuscan Domain this sequence records a major marine transgression (Figs 2 & 12) starting during the Carnian with lagoonal, mixed carbonate–siliciclastic–evaporitic deposits (Tocchi Formation), followed by siliciclastic-free evaporites and carbonates (Boccheggiano Anhydrite). The transition to the Lower Liassic Massiccio Limestone is marked by the deposition of carbonates with thin shale intercalations (*Rhaetavicula contorta* beds) in a wide metahaline lagoon.

In the Internal Tuscan Domain (Apuane Alps and Massa Zone), a carbonate platform developed during the Norian under an arid climate (Grezzoni Dolomite), locally directly on the basement. It inter-fingers to the west with a calcareous marly sequence laid down in a deepening-upward basin (La Spezia Formation) which persisted through Lower Liassic with the deposition of the Ferriera Formation. Elsewhere a carbonate platform developed under a humid climate (Massiccio Limestone) and this was later drowned and covered by open–marine neritic deposits (Ammonitico Rosso and Cherty Limestone).

### Tocchi Formation (Carnian)

This formation consists of alternating sericitic and chloritic shales and thin dolomites (up to 40 m thick) passing upward to evaporite solution breccias (Figs 2 & 9). Rare and poorly preserved foraminifera (*Glomospira* cf. *kuthani*, *Diplotremina* sp. and *Glomospirella* spp.) suggest a Carnian age (Costantini *et al.*, 1980). They formed in restricted lagoons located along an arid shoreline (Costantini *et al.*, 1980).

### Boccheggiano Anhydrite (Carnian to Norian)

A thick evaporitic sequence (up to 1000 m), known in Tuscany as Boccheggiano Anhydrite, Burano Formation or Cavernoso Limestone (Calcere cavernoso), overlies the Tocchi Formation and underlies the *Rhaetavicula contorta* beds (Figs 2 & 9). Boccheggiano Anhydrite (Anidriti di Boccheggiano) is an informal name commonly given to the Triassic anhydrite–carbonate unit that in the

subsurface of Boccheggiano (southern Tuscany) overlies the Palaeozoic Boccheggiano Formation (Costantini *et al.*, 1980). Burano Formation is an Umbrian unit. In Tuscany the authors commonly refer to the evaporitic sequence as the Burano Formation when found sheared off at the base or locally enclosed in the Ligurian nappes. Recent research on foraminiferal assemblages of both the Burano Formation and Boccheggiano Anhydrite, suggests different microfaunal provinces and a different age range (Norian to Rhaetian) for Burano Formation (Martini *et al.*, 1989). The Boccheggiano Anhydrite ranges from Carnian with *Triadodiscus eomesozoicus*–*Glomospirella capellinii* assemblages to Norian with *Glomospirella rosetta*–*Gandinella apenninica* assemblages (Zaninetti, pers. comm.). This unit consists of alternating layers of anhydrite and early dolomite. The Cavernoso Limestone is a dolomitic breccia with abundant calcite cements. It resulted from anhydrite–gypsum–anhydrite changes induced by Alpine tectonic stresses, and subsequent dissolution of the sulphates during exposure and weathering. It mostly represents the evaporitic sequence in outcrop whereas in the subsurface the sulphates and the stratigraphic order are better preserved (Costantini *et al.*, 1983; Martini *et al.*, 1989).

The carbonate facies are stromatolites and mudstone with anhydrite rosettes and nodules (Fig. 6c,d), wackestone with faecal pellets and skeletal grains, and fine-grained intraclast or oolitic grainstone. They indicate an arid low-energy intertidal–supratidal environment corresponding to a sabkha system (Martini *et al.*, 1989).

### Grezzoni Dolomite (Carnian to Rhaetian)

#### Grezzoni Dolomite

This is a dolomite unit up to 300 m thick that overlies the Tocchi Formation (Montagnola Senese) or lies directly on the Palaeozoic basement (Apuane Alps). It grades upward to the Massiccio Limestone. Westward of the Apuane Alps, in the La Spezia region, Grezzoni Dolomite inter-fingers with La Spezia Formation (Ciarapica & Passeri, 1980). Early Jurassic Massiccio Limestone and Ferriera Formation are respectively superposed over Grezzoni Dolomite and La Spezia Formation (Figs 2 & 9).

La Spezia Formation consists of two members: the Norian Monte S. Croce Member and the

Rhaetian Portovenere Member. The facies are mostly mudstones associated with skeletal wackestone and packstone including low diversity bivalve assemblages and oolites in the lower part, and *Triasina hantkeni* and radiolarians in the upper part (Ciarapica & Zaninetti, 1984).

The Grezzoni Dolomite includes poorly diversified fossil associations of *Worthenia escheri*, megadontids, dasycladacean algae (*Gyroporella*, *Physo-porella*, *Diplopora*) and foraminifera. The last are found in two superposed assemblages, the first is Norian with *Agathammina australpina* and Glomospirellas, the second, Rhaetian with *Trasina hantkeni* and *Involutinas* (Ciarapica & Passeri, 1978).

The facies, consisting of oolitic and skeletal grainstone, wackestone with foraminifera, mudstone and stromatolites, document an arid setting in a shallow subtidal to supratidal depositional system (Ciarapica & Passeri, 1978). The Grezzoni Dolomite is bounded to the west by an oolitic shoal flanked by the deeper water of the La Spezia basin (Fig. 12). To the east the tidal flats graded to an hypersaline lagoon whose sediments probably passed into the Boccheggiano Anhydrite although evidence of this transition is missing because of the structural setting of the region (Ciarapica & Passeri, 1978; 1980).

#### *Rhaetavicula contorta* beds (Rhaetian)

This unit, 60–100 m thick, consists of black limestone, alternating with black shales which gradually disappear in the upper part (Figs 2 & 9). Gradational boundaries exist with the underlying evaporitic sequence and the overlying Massiccio Limestone. The black limestone facies consists of mudstone, commonly with anhydrite and celestite pseudomorphs, bioclastic packstone and grainstone, and stromatolites. Fossils, locally very abundant, form low-density assemblages dominated by bivalves (*Rhaetavicula contorta*) and foraminifera (*Triasina hantkeni*) diagnostic of Rhaetian.

In the Monte Cetona area of southeastern Tuscany the upper part of the *Rhaetavicula contorta* beds are characterized by skeletal banks with *Megalodon* and dasycladacean algae and mounds built by encrusting organisms and stromatolites (Ciarapica *et al.*, 1982). The depositional setting represents a confined, wide metahaline lagoon bounded to the east by low-relief shoals (Fig. 12).

The Upper Triassic sequences of Tuscany were deposited under an arid climate in a complex en-

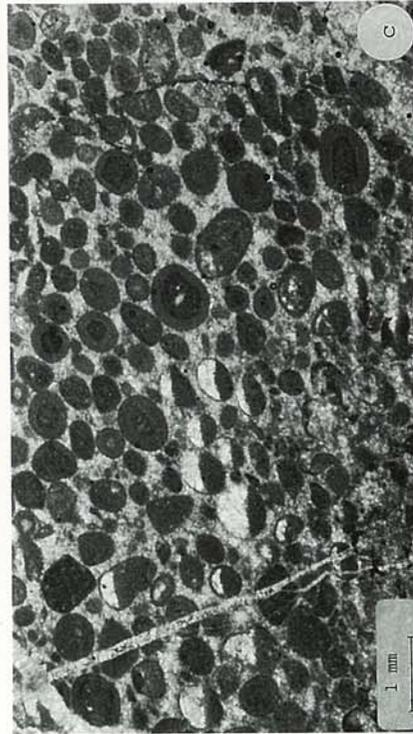
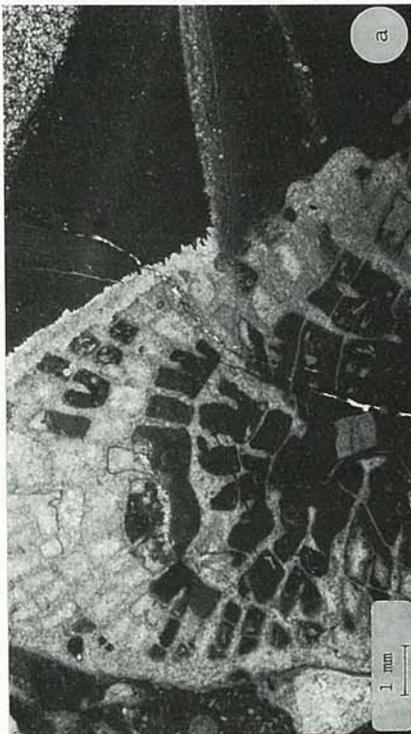
vironmental setting. On the structural highs (Apuane Alps, Montagnola Senese) the Grezzoni Dolomite tidal-flat system developed; it was bounded to the west by an epicontinental basin and to the east it graded to a depressed, more subsident area, in which during Carnian and Norian, sulphate deposition prevailed over the carbonates (Boccheggiano Anhydrite), and during Rhaetian this was replaced by a wide metahaline lagoon (*Rhaetavicula contorta* beds). The areal distribution of the facies and the lack of terrigenous material in both the carbonate and evaporitic sequences document a wide platform detached from the emergent land, whose morphology was initially controlled by the basement structural pattern (Fig. 12).

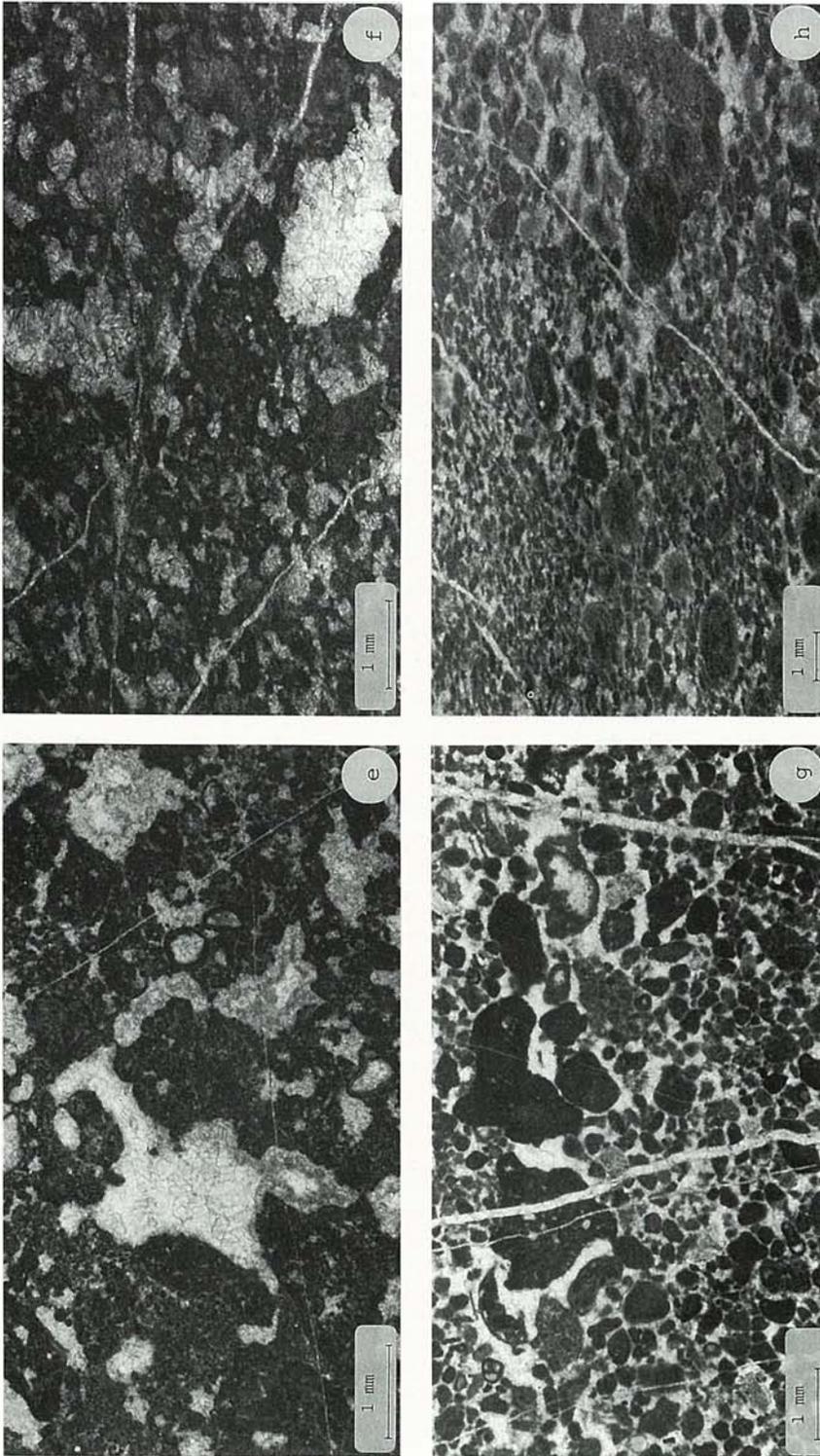
#### Massiccio Limestone (Lower Liassic)

This unit consists of a massive body of pure white limestone whose thickness ranges from 50 to 1000 m. At the base it is bounded by the Grezzoni Dolomite or the *Rhaetavicula contorta* beds, and by Ammonitico Rosso at the top (Boccaletti *et al.*, 1975; Fazzuoli, 1974a, b) (Figs 2 & 9). While the lower boundary is gradational, the upper one is unconformable and is marked by an abrupt contact between the white massive limestone and the pink bedded marly limestone of Ammonitico Rosso.

The Massiccio Limestone is locally affected by recrystallization and minor dolomitization. In its upper part neptunian dykes, karstic features and calcite veins are common (Fazzuoli *et al.*, 1981). Common fossils are gastropods, bivalves, ostracods and arenaceous foraminifera. Solenoporacean and dasycladacean algae (*Palaeodasycladus mediterraneus* and *Thaumatoporella parvovesiculifera*), brachiopods, corals, echinoderms, sponge spicules and *Spirillina liassica* are locally common. They document normal-marine waters and a general Liassic age.

Westward of the northern Apuane Alps, the Massiccio Limestone interfingers with the Ferriera Formation that is an ammonite-rich calcareous unit containing *Schlotheimia angulata* whose age is Hettangian. Elsewhere in Tuscany, the age of the Massiccio Limestone is assumed to be Hettangian on the basis of the age of the underlying and overlying units (Giannini *et al.*, 1972). The Massiccio Limestone displays a greatly variable thickness in adjoining sections and a complex internal stratigraphy (Boccaletti *et al.*, 1975; Fazzuoli, 1974a, b) resulting from repeated vertical and lateral facies





**Fig. 7.** Humid platform. Lower Cambrian Ceroid Limestone (right) and Lower Liassic Massiccio Limestone (left). (a) Mud mound with corals. (b) Buildup with algae (*Epiphyton*) and archaeocyathids. (c). (d) Oolitic grainstone; larger coated grains and skeletal remains occur in the Cambrian facies, whose grains are badly deformed. (e), (f) Fenestral fabric in stromatolitic boundstone, irregular fenestrae are filled by two generations of cement. (g), (h) Grainstone with calcrete grains and grapestone lumps; peloids and skeletal remains are associated with the Jurassic facies.

changes (Fig. 5). The following facies have been recognized:

**1 Tidal flat.** Fenestral stromatolitic boundstone (Fig. 7e), beach-rock and vadose pisolite (*sensu* Esteban, 1976). The stromatolitic boundstone is built by encrusting microbial organisms and algae (*Thaumatoporella*). Arenaceous foraminifera, gastropods and ostracods are rare.

**2 Internal lagoon.** Prevailing mudstone and peloidal–skeletal wackestone, with faecal pellets, ostracods and arenaceous foraminifera.

**3 Shoal.** Three different facies have been recognized: type (1) consists of well-sorted oolitic (Fig. 7c) or oolitic–oncolitic grainstone with lumps; type (2) corresponds to crinoid–coral mounds (Fig. 7a). Associated fossils in both facies are corals, solenoporacean and dasycladacean algae, molluscs, brachiopods and rare foraminifera. Type (3) is peloidal–intraclast or unsorted–intraclast grainstone (Fig. 7g). Molluscs, echinoderms and rare algae (*Paleodasycladus*, *Solenopora* and *Thaumatoporella*) are found in the intraclasts, as well as sponge spicules and open-marine foraminifera (*Spirillina liassica*).

**4 Open lagoon.** Skeletal wackestone with pelagic organisms such as ammonites, radiolarians and foraminifera, and locally reworked calcrete clasts and marly intercalations.

These facies have a non-cyclic vertical distribution and are laterally discontinuous (Fig. 5). A regressive trend at the top of the sequence occurs only in some sections of the platform interior. The areal distribution of the facies indicates an isolated platform bounded by epicontinental basins (Boccaletti *et al.*, 1975; Fazzuoli, 1980). From west to east the following facies equivalent zones can be recognized (Fig. 1).

**1 Epicontinental basin.** The Massiccio Limestone is here replaced by stratified, open-marine facies (Ferriera Formation). In northern Apuane Alps, where the Massiccio Limestone thins out, these strata interfinger in the slope zone off the Massiccio platform.

**2 Platform-rimmed margin.** This is built by oolitic shoals and locally by crinoidal–coral–mounds (type (1) and (2) shoal facies).

**3 Platform interior.** This consists of irregularly alternating, restricted-lagoon and tidal-flat facies.

**4 Platform ramp-like margin.** Type (3) shoal facies containing intraclasts with pelagic organisms interfingers with open-lagoon facies.

### Ammonitico Rosso (Middle Lias)

The Ammonitico Rosso lies unconformably on the Massiccio Limestone. The contact is sharp and is locally marked by karstic breccias (Figs 2 & 9). This unit comprises three, irregularly alternating lithotypes: (1) pink, locally laminated limestone with local ammonite and/or crinoidal lumachelles (Calcare rosa a Crinoidi), commonly found at the base of the sequence; (2) red nodular marly limestone (Fig. 8c) with shaly partitions and local concentrations of ammonites (Calcare rosso ammonitico), recurring at different stratigraphic levels; and (3) grey cherty limestone (Cherty Limestone–Calcare selcifero) with thin argillaceous interbeds commonly prevailing in the upper part of the sequence (Fazzuoli & Pirini Radrizzani, 1981). Locally breccias and megabreccias of Calcare Massiccio blocks are found, enclosed in the Cherty Limestone (Fazzuoli, 1974b). The facies (Fig. 8d) are mudstone, skeletal wackestone, and packstone with crinoid plates, ammonites, radiolarians, sponge spicules and foraminifera which indicate an open-marine environment.

Ammonite assemblages document different stratigraphic levels: the older with *Arietites listeri* (*Arietites bucklandi* biozone) is Lower Sinemurian. Upper Sinemurian is documented by faunas with *Eoderoceras olenophyichum* whereas the younger assemblages with *Coeloceras psiloceroides*, *Amaltheus margaritatus* and *Protogrammoceras algovianum* record Pliensbachian (Federici, 1967). Higher in the sequence the Cherty Limestone grades into marls with pelagic bivalves (*Posidonomia alpina* Marls, Toarcian–Aalenian) that in turn pass to basinal, turbiditic siliceous shales and cherts (Diaspri, Dogger–Malm). These in the Ligurian Domain are associated with ophiolites.

### Post-depositional processes

The Massiccio Limestone underwent extensive freshwater cementation. Cements mostly consist of blocky calcite whereas marine cements are poorly developed and locally show traces of dissolution. In the upper part of the unit neptunian dykes (6–8 m wide) and paleokarstic features are common. They are well developed along the western margin of the Massiccio platform and less common, but larger along the eastern margin. Breccia bodies are enclosed in karstic cavities or in the Cherty Limestone (Fazzuoli, 1980; Fazzuoli *et al.*, 1981).

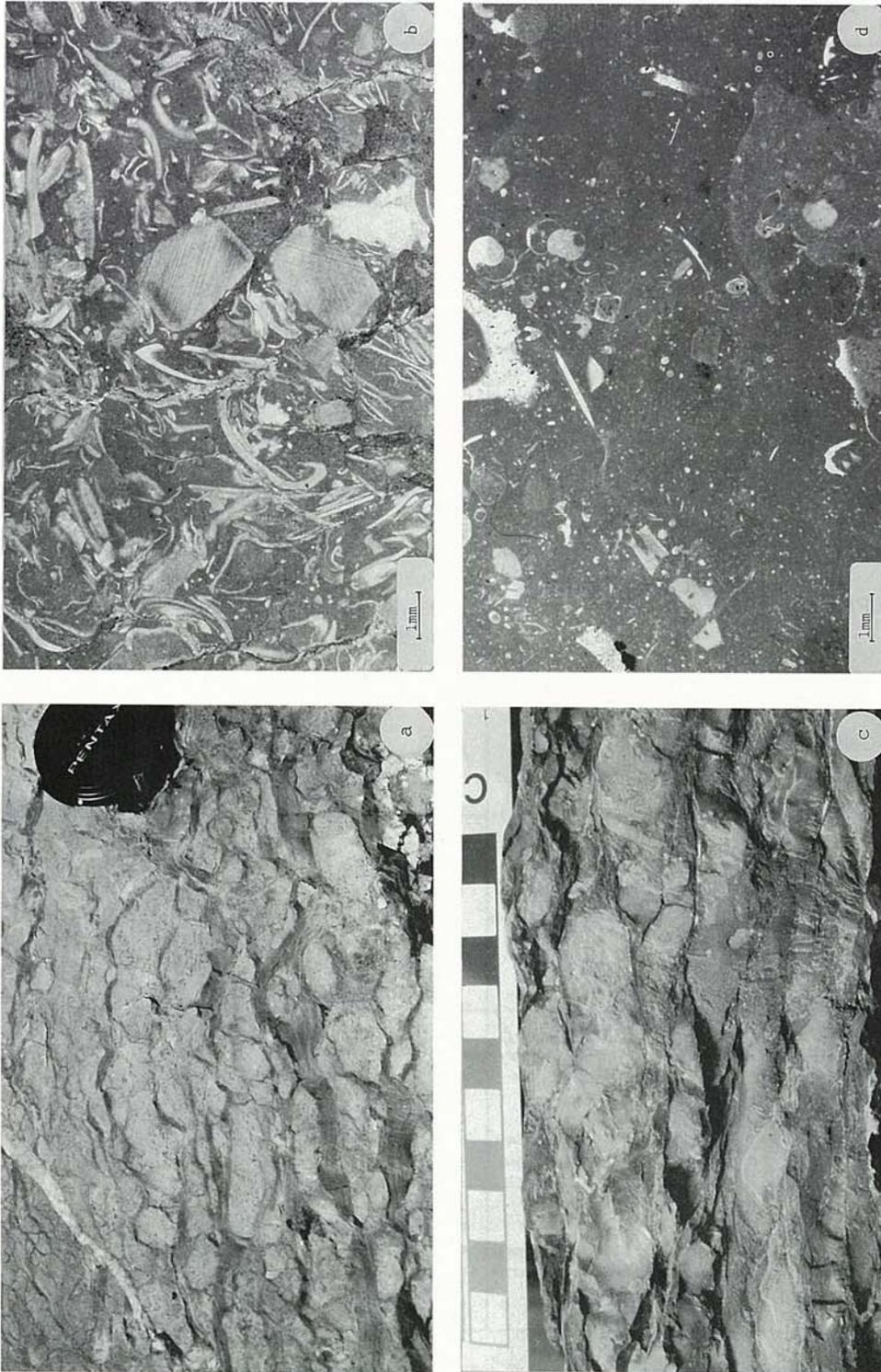


Fig. 8. Nodular facies. Middle Cambrian Cabitza Limestone and Middle Liassic Ammonitico Rosso (below). (a), (b) Limestone consisting of skeletal packstone with trilobite and echinoderm debris. (c), (d) Limestone consisting of wackestone with ammonites, echinoderms and sponge spicules.

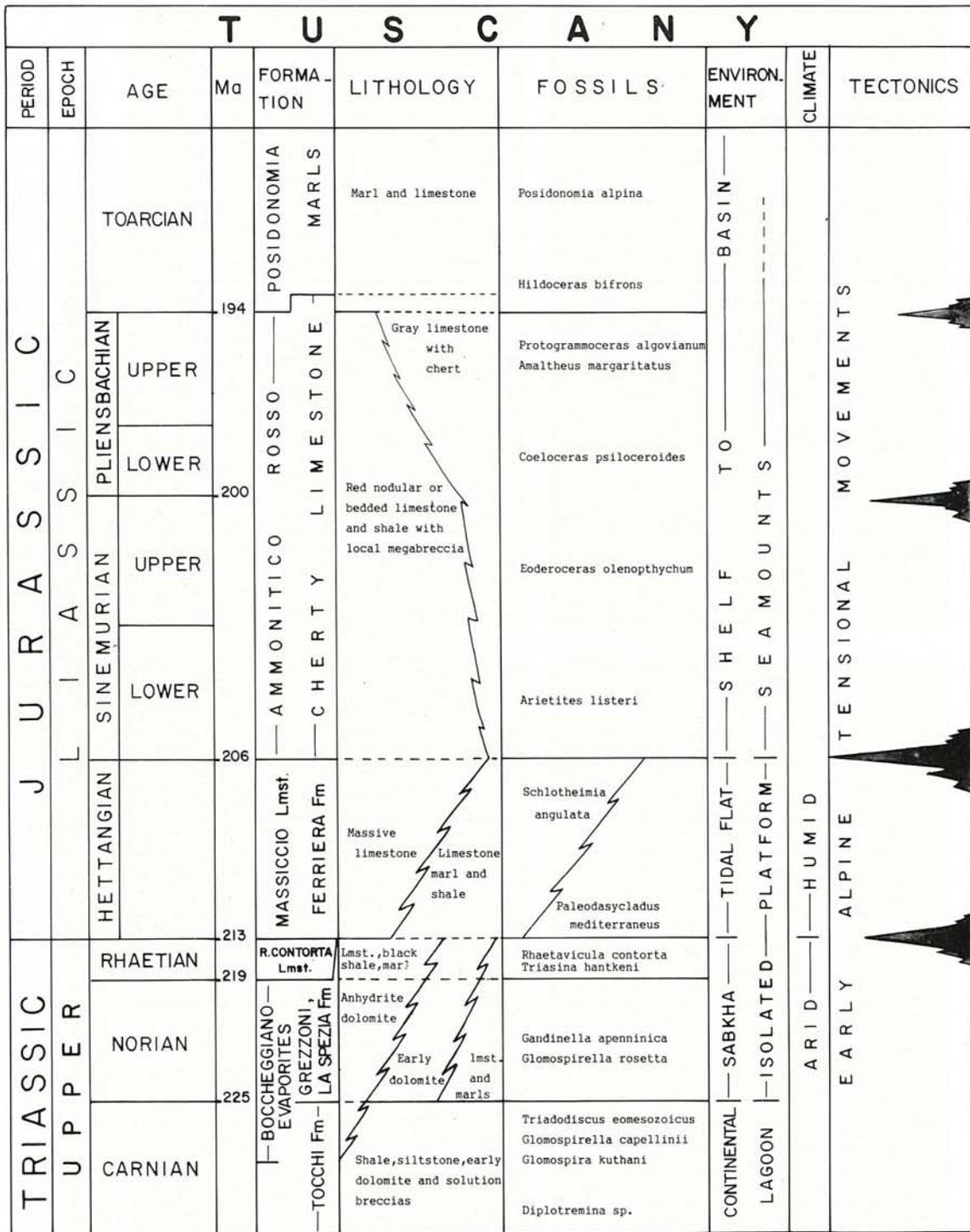


Fig. 9. Stratigraphy, depositional environments and tectonic events of the carbonate platform in Tuscany.